Thermosphere-Ionosphere-Mesosphere Modeling Using the TIME-GCM

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LONG-TERM GOALS

A major goal of the research is to understand how elements in the coupled upper atmosphere/ ionosphere system interact with one another and to determine how this coupled system responds to the variable energy input from the sun and the variable input from the lower atmosphere and ocean. The research focuses on understanding the sources and characteristics of global-scale ionospheric, thermospheric, and mesospheric structure and variability and the coupling of those atmospheric regions to the lower atmosphere and to the magnetosphere and solar wind.

OBJECTIVES

Our scientific objectives are to understand the nature of the sources of variability in the upper atmosphere/ionosphere system and how they are related to solar radiative and auroral particle and electric field forcings. We are also interested in understanding how disturbances from the lower atmosphere and ocean affect the upper atmosphere and how this variability interacts with the variability generated by solar and auroral sources. We accomplish this task by developing large-scale numerical models of the upper atmosphere and ionosphere and using these models to analyze data obtained by satellites and ground-based observatories as well as using these models for numerical simulations to understand how upper atmosphere/ionosphere physics and chemistry interact. We are also developing and using a model of the whole atmosphere extending between the ground and 500 km for use in simulating and analyzing atmospheric variability and for studying solar and auroral influences on the entire atmosphere.

APPROACH

A hierarchy of numerical models has been developed that describes the upper atmosphere and ionosphere and these models have been used to study atmosphere/ionosphere interactions and their response to solar and auroral variability for over 20 years. The current version of models include: the TIE-GCM, TIME-GCM, and flux-coupled TIME-GCM/CCM3, where the I, M, and E represent "ionosphere," "mesosphere," and "electrodynamics," respectively. The CCM3 is the NCAR Community Climate Model, Version 3.6, a GCM of the troposphere and stratosphere. All models include self-consistent ionospheric electrodynamics, that is, a calculation of the electric fields and currents generated by the ionospheric dynamo, and consideration of their effects on the neutral dynamics. The TIE-GCM is used for studies that focus on the thermosphere and its coupling with the

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14. ABSTRACT
A major goal of the research is to understand how elements in the coupled upper atmosphere/ ionosphere system interact with one another and to determine how this coupled system responds to the variable energy input from the sun and the variable input from the lower atmosphere and ocean. The research focuses on understanding the sources and characteristics of global-scale ionospheric, thermospheric, and mesospheric structure and variability and the coupling of those atmospheric regions to the lower atmosphere and to the magnetosphere and solar wind.

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ionosphere and magnetosphere. The TIME-GCM, the most elaborate of the upper-atmospheric TGCMs, solves for global distributions of neutral and plasma temperatures, velocities, and compositions, including all of the species that are photochemically important in the mesosphere, thermosphere, and ionosphere. The flux-coupled TIME-GCM/CCM3 is an exploratory climate model that extends from the ground, including oceans, to 500 km altitude to study global atmospheric variability and couplings.

A project is underway to extend the current NCAR Climate Systems model to include the thermosphere and ionosphere up to an altitude of 500 km. This Whole Atmosphere Community Climate Model (WACCM) is a continuous model of the entire atmosphere compared with the flux-coupled TIME-GCM/CCM3 where 2 independent models are coupled at a free surface in the atmosphere (10 mb).

In addition to the above models we also use the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) to provide auroral inputs and a Global Scale Wave Model (GSWM) to study tides and planetary wave propagation in the atmosphere. The latter is a linearized model that is useful in helping understand tidal and wave phenomena in the non-linear TGCMs. We also have a small-scale gravity wave model to examine processes and develop parameterizations of these processes for inclusion in the global models.

NCAR personnel participating in this work include: Raymond G. Roble (aeronomy and global upper atmosphere and ionospheric dynamics), Arthur D. Richmond (electrodynamics and upper atmosphere waves), Hanli Liu (gravity wave parameterizations), Maura E. Hagan (tides and planetary waves), Barbara A. Emery and Gang Lu (campaign studies and data analysis), and Benjamin Foster (programming support and model development). The Whole Atmosphere Community Climate Model (WACCM) is a collaborative effort between three NCAR Divisions: The High Altitude Observatory (HAO), the Climate and Global Dynamics Division (CGD), and the Atmospheric Chemistry Division (ACD).

WORK COMPLETED

For the TIE-GCM we continue to modify and improve the model so that it can run in a multi-tasked mode and be machine portable. We have converted the model output to netCDF files so that the results can be easily accessed and used by our collaborators. We have also modified our processors and developed many new diagnostics of model output for direct comparison with satellite and ground-based data.

We have extended the model’s capability to perform time-dependent space weather studies that include time varying solar EUV and UV flux variations as well as variations of auroral inputs and ionospheric convection. The solar radiative inputs vary with the solar F10.7 and auroral inputs vary as the 3 hr Kp index. The model, for campaign studies, can also accept inputs from the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) analysis.

The TIME-GCM has also been modified for time-dependent solar and auroral forcings as well as including NCEP data at the lower boundary (10 mb). These time-dependent forcings have been used in a model run for the entire year 1993. The TIME-GCM has also been run for the CRISTA1&2/

MAHRSI1&2 Shuttle experiment periods and the results have been used to analyze and interpret the satellite data.

Recognizing that many of the problems regarding atmospheric and ionospheric variability can best be addressed with a model that extends from the ground to the exosphere, we are continuing the development of a Whole Atmosphere Community Climate Model (WACCM). WACCM is currently a global model of the atmosphere from the ground to the lower thermosphere (140 km), designed to investigate solar-terrestrial coupling and climate issues; we anticipate that the model will eventually extend to 500 km. WACCM integrates three proven and well-tested models developed by NCAR and the scientific community: (1) the middle atmosphere version of the NCAR Community Climate Model, (2) the NCAR TIME-GCM, and (3) the Model for Ozone and Related Chemical Tracers (MOZART). The current version of the model has run successfully for 30 years simulation time and the results have produced several new findings, one of which is discussed below.

RESULTS

The results from some of the studies conducted during the past year include the following:

- A significant new finding during the past year was that sea surface temperature had an important impact on the structure of the winter stratosphere, mesosphere and lower thermosphere as well as in the region of the summer mesopause. Simulations made with WACCM with and without changes in sea surface temperature indicated considerable difference in the structure of these regions. In particular, the difference between the years 1991 (El Niño) and 1989 (La Niña) showed a temperature increase of nearly 10K in the winter stratosphere and a cooling of 10K in the winter mesosphere and a warming of 5K in the lower thermosphere near 120 km. In addition, there was a significant warming of the summer mesopause region of up to 7K. The only changes between the two simulations were changes in sea surface temperature in El Niño and La Niña conditions. The TIME-GCM was also run for those two years using NCEP forcings obtained from observations at 10 mb near 30 km. The results were nearly identical to the WACCM results and also indicated compositional changes in the mesosphere and lower thermosphere. There is some observational evidence supporting these calculations. In 1991, the sighting of noctilucent clouds was suppressed considerably during the El Niño period consistent with a warmer summer mesopause than usual.

  These results show significant coupling between the lower and upper atmosphere and the need for a model of the whole atmosphere.

- The TIME-GCM calculates the global distribution of temperature, winds and composition of the upper atmosphere between 30 and 500 km altitude. Carbon Dioxide (CO_2) is one of the species that the model predicts, and it is very important for determining the energy budget of the mesosphere and thermosphere and for various limb sensing purposes for satellite orientation.

  The model calculations of CO_2 include chemistry, molecular and eddy diffusion and transport by the winds that are important for determining the altitude distribution of the CO_2 mixing ratio. The TIME-GCM calculations have always shown a rapid decrease of CO_2 mixing ratio, from its constant value of 350 ppmv in the lower atmosphere, around 75-80 km, whereas other models of middle atmosphere chemistry and dynamics always had constant values to about 100 km before the mixing ratio began decreasing slowly with altitude. The TIME-GCM values were shown to agree with the available observations of CO_2 mixing ratio from rocket flights, the CRISTA 2 satellite data, and other observations (Lopez-Puertas et al., 2000) whereas other middle atmosphere models did not. The reason for the much more rapid decrease of mixing ratio with altitude was shown to be caused by the model having molecular diffusion, whereas other models only included eddy diffusion. It was thought that the effects of molecular diffusion only became important at the turbopause near 105 km and therefore it was not included in these models. The TIME-GCM calculations that included molecular diffusion had an influence much lower than the turbopause. The TIME-GCM also predicted a latitudinal distribution to the transition height where the mixing ratio begins to decrease rapidly. In the summer hemisphere polar region this transition occurs near 90 km whereas in the winter hemisphere polar region the transition occurs as low as 60 km, primarily because of the downward transport of lower thermospheric and mesospheric air, having low mixing ratios, into the winter polar vortex. This finding has important implications for the energy budget of the mesosphere and lower thermosphere because 15 micron CO_2 radiation is the dominant heat loss mechanism in this region of the atmosphere. It is also important to understand the distribution of CO_2 because of possible global change in the mesosphere and lower thermosphere.

- Stratospheric Sudden Warmings (SSW) have been of great research interest because they signify a pronounced change in the atmospheric general circulation during a relatively short period of time. They are believed to be caused by an interaction of planetary waves with the mean circulation. The planetary waves are believed to originate in the troposphere, but the impacts of such events extend well into the mesosphere. The coupled NCAR thermosphere-ionosphere-mesosphere-electrodynamics general circulation model and NCAR community climate model (TIME-GCM/CCM3) (Roble, 2000) has been used to study a self-generated stratospheric sudden warming: its source, development, changes in the middle atmosphere circulation, and the dynamical and aeronomic impacts on the mesosphere/lower thermosphere (MLT). The SSW event took place in January of the third year of a coupled simulation. Model results show that a quasi-stationary wave number 1 mode develops spontaneously in the troposphere and lower stratosphere polar region. This wave propagates upward and poleward growing in amplitude until a maximum occurs at about 60 km altitude. The model shows a peak temperature increase of 40K between 45-50 km in the polar region and a maximum temperature decrease of ~60K at around 80 km. Furthermore, the change of the stratospheric jet from eastward to westward also changes the filtering of gravity waves and causes a significant decrease of atomic oxygen in the lower thermosphere.

  All models that have studied the atmospheric response to SSWs have had their upper boundary in the stratosphere or mesosphere all below 100 km. The TIME-GCM extends upward to 500 km and is thus able to examine how the thermosphere and ionosphere responds to such events.

- The TIME-GCM has been used to study changes in dynamics in the mesosphere and lower thermosphere around spring and fall equinoxes. Both ground based and satellite observations have shown a “springtime transition” in the night-time oxygen airglow emission rates with a sharp net decrease over several days around spring equinox, indicating a depletion of atomic oxygen. Similar changes are also found in the TIME-GCM year-run simulations. A diagnostic analysis of the simulation and showed that changes in the dynamical processes in the mesosphere/lower thermosphere (MLT) regions can cause the depletion of atomic oxygen and a significant decrease in the airglow intensity.

Northern hemisphere planetary waves are strong in the winter and weak in the summer, and they go through a fast transition around equinox. The planetary wave movement during the transition and its effect on the temperature and winds in the mesosphere are significant. The simulated planetary wave structure agrees with climatological studies and the fast transition of the planetary waves is captured by the model. The wave variability produces large temperature changes in the upper atmosphere above local stations in middle and high latitudes. The qualitative behavior of the model are in agreement with OH mesospheric temperature measurements above the Ft. Collins, CO station for one of the periods that was studied in detail.

- The influence of dynamics on the distribution of minor constituents in the MLT region are being analyzed by the TIME-GCM. Satellite analyzed nitric oxide observations from the UARS Halogen Occultation Experiment indicate that the observed diurnal variations in mesospheric nitric oxide, previously thought to be anomalous, are the result of transport by the atmospheric solar diurnal tides.

Web site for the Thermospheric General Circulation Models:
http://www.hao.ucar.edu/public/research/tiso/tgcm/tgcm.html

Web site for the AMIE electric potential patterns for selected space weather events:
http://www.hao.ucar.edu/public/research/tiso/amie/AMIE_head.html

Web site for the January 97 TIE-GCM movies:
http://www.hao.ucar.edu/public/research/tiso/tgcm/jan97_movies/jan97_movies.html

Web site for the JWACCM model:
http://acd.ucar.edu.models/WACCM

IMPACT/APPLICATIONS

The models we have developed are community models and they have been used by over 100 scientists and students over the past few years. Thus, the models are constantly being evaluated, upgraded and improved by community feedback. We participate in NRL studies, NSF Coupling and Energetics of Atmospheric Regions (CEDAR), Geospace Environmental Modeling (GEM), and Space Weather Initiative (SWI) programs. The models have been used for the Navy ARGOS satellite mission, the NASA Sun-Earth Connection Theory Program, the Atmosphere Explorer (AE), Dynamics Explorer (DE), Solar Mesosphere Explorer (SME), Upper Atmosphere Research Satellite (UARS), and the Global Geospace Study (ISTP/GGS) NASA satellite missions as well as U.S. Air Force and Navy satellite missions. We have also participated in the CRISTA and MAHRSI space shuttle experiments. We also participate in the NCAR Climate Systems Modeling effort in examining the couplings between the upper and lower atmospheres and in an attempt to understand the effects of the variable solar outputs on the coupled Earth system. We have also developed a model of the whole atmosphere (WACCM) that is useful for studying couplings between the atmosphere and ocean and the response of the entire atmosphere to solar-terrestrial couplings.

TRANSITIONS

There have been no transitions thus far with the contract. The models are being developed for eventual ONR and Space Weather studies.

RELATED PROJECTS

The numerical modeling effort is complemented by a data analysis and interpretation effort. Data from the following satellites have been analyzed and compared with model simulations:

- Navy ARGOS mission
- NASA Dynamics Explorer mission
- NASA Upper Atmosphere Research Satellite (UARS)
- NASA CRISTA and MAHRSI experiments aboard the space shuttle
- NASA ISTP/GGS satellite mission
- NSF CEDAR campaigns
- NSF GEM campaigns

PUBLICATIONS

Lopez-Puertas, M., M. A. Lopez-Valverde, R. R. Garcia, and R. G. Roble, A review of CO and CO2 abundances in the mesosphere and lower thermosphere, “Atmospheric Science Across the Stratopause,” *Geophysical Monograph*, **123**, American Geophysical Union, 83-100, 2000.

Roble, R. G., On the feasibility of developing a global atmospheric model extending from the ground to the exosphere, “Atmospheric Science Across the Stratopause,” *Geophysical Monograph*, **123**, American Geophysical Union, 53-67, 2000.

Sharma, R. D. and R. G. Roble, “Impact of the new rate coefficients for the O atom vibrational deactivation and photodissociation of NO on the temperature and density structure of the terrestrial atmosphere,” *J. Geophys. Res.*, in press, 2000.

Walterscheid, R. L., G. G. Sivjee, and R. G. Roble, “Mesospheric and lower thermospheric manifestations of a stratospheric warming event over Eureka, Canada (80N),” *Geophys. Res. Lett.*, **27**, 2897-2900, 2000.

Fesen, C. G., D .L. Hysell, J. W. Meriwether, M. Mendillo, B. G. Fejer, R. G. Roble, B. W. Reinisch, and M. A. Biondi, “Modeling the low latitude atmosphere and ionosphere,” *J. Atmos. and Solar-Terr. Phys.*, in press 2001.

Hagan, M. E. and R. G. Roble, “Modeling diurnal tidal variability with the NCAR TIME-GCM,” *J. Geophys. Res.*, in press, 2001.

Hagan, M. E., R. G. Roble, and J. Hackney, “Migrating thermospheric tides,” *J. Geophys. Res.*, **106**, 12,739-12,752, 2001.

Hagan, M. E., R. G. Roble, C. Hartsough, J. Oberheide, and M. Jarisch, “The dynamics of the middle atmosphere during CRISTA-2 as simulated by the NCAR TIME-GCM,” *J. Geophys. Res.*, in press, 2001.

Immel, T .J., G. Crowley, J. D. Craven, and R. G. Roble, “Dayside enhancements of thermospheric O/N2 following magnetic storm onset,” *J. Geophys. Res*., **106**, 15,471-15,488, 2001.

Liu, H.-L., R. G. Roble, and M. J. Taylor, “Mesospheric planetary waves at Northern Hemisphere fall equinox,” *Geophys. Res. Lett*., **28**, 1903-1906, 2001

Lu, G., A. D. Richmond, R. G. Roble, and B. A. Emery, “Coexistence of ionospheric positive and negative storm phases under northern winter conditions: A case study,” *J. Geophys. Res*., in press, 2001.

Lu, G., A. D. Richmond, R. G. Roble, and B. A. Emery, “Ionospheric-thermospheric response to the January 1997 geomagnetic storm,” *J. Geophys. Res.*, in press, 2001.

Marsh, D. and R. G. Roble, “TIME-GCM simulations of lower thermospheric nitric oxide seen by the Halogen Occultation Experiment,” *J. Atmos. and Solar-Terr. Phys*., in press, 2001.

Meier, R .R., J. M. Picone, D. P. Drob, and R. G. Roble, “A similarity transformation for use with atmospheric models, data and inverse remote sensing problems,” *J. Geophys. Res*., **106**, 15,519-15,532, 2001.

Peymirat, C., A. D. Richmond, and R. G. Roble, “Neutral wind influence on the electrodynamic coupling between the ionosphere and magnetosphere,” *J. Geophys. Res*., in press, 2001.

Roble, R. G., On forecasting thermospheric and ionospheric disturbances in space weather events, “Space Weather,” *Geophysical Monograph*, **125**, American Geophysical Union, 369-376, 2001.

Taylor, M. J., W. R. Pendleton, Jr., L. C. Gardner, H.-L. Liu, R. G. Roble, C. Y. She, and V. Vasoli, “Large amplitude perturbations in mesospheric OH Meinel temperatures around the autumnal equinox transition period,” *Geophys. Res. Lett.*, **28**, 1899-1902, 2001.

Thuillier, G., R. H. Wiens, G. G. Shepherd, and R. G. Roble, “Photochemistry and dynamics in thermospheric intertropical arcs measured by the WIND Imaging Interferometer on board UARS,” *J. Atmos. and Solar-Terr. Phys.*, in press, 2001.

Zhang, S. P., R. G. Roble, and G. G. Shepherd, “Tidal influence on the oxygen and hydroxyl nightglows: WINDII observations and TIME-GCM simulations,” *J. Geophys. Res.*, in press, 2001.

PRESENTATIONS IN FY2001

"Climate of the stratosphere-mesosphere-lower thermosphere using interacting dynamics and chemistry in a GCM," F. Sassi, D. Kinnison, B. Bovile, R. R. Garcia, and R. G. Roble, paper presented at the SPARC symposium, November 2000, Argentina.

"A coupled MHD-TIEGCM simulation of the ionosphere-magnetosphere coupling," A. Ridley, D. DeZeeuw, R. Clauer, T. Gombosi, K. Powell, A. Richmond, and R. G. Roble, paper presented at the Annual Fall AGU meeting, December 15-19, 2000, San Francisco, CA.

"Description and application of the Whole Atmosphere Community Climate Model (WACCM) to the mesosphere and lower thermosphere," D. Kinnison, F. Sassi, B. G. Boville, R. R. Garcia, and R. G. Roble, invited paper presented at the Annual Fall AGU meeting, December 15-19, 2000, San Francisco, CA.

"Evidence for large amplitude perturbations in mesospheric OH Meinel temperature around the autumnal equinox transition period," M. J. Taylor, W. R. Pendleton, Jr., L. C. Gardner, C. Y. She, V. Vasoli, H.-L. Liu, and R. G. Roble, paper presented at the Annual Fall AGU meeting, December 15-19, 2000, San Francisco, CA.

"Space weather effects in the lower thermosphere," M. E. Hagan, R. G. Roble, and C. G. Hartsough, paper presented at the Annual Fall AGU meeting, December 15-19, 2000, San Francisco, CA.

"Modeling the mesosphere, lower thermosphere," R. G. Roble, invited paper presented at the TIMED Pre-Launch Science Workshop, April 25, 2001, Boulder, CO.

"A seasonal climatology of lower thermospheric winds derived from incoherent scatter measurements obtained during lower thermosphere coupling study experiments," R. M. Johnson, A. I. Azeem, C. G. Fesen, L. P. Goncharenko, M. Hagan, S. Nozawa, R. G. Roble, and Q. Zhou, paper presented at the Annual Spring AGU meeting, May 29-June 1, 2001, Boston, MA.

"Nitric oxide in the mesosphere and thermosphere: Dynamical coupling and vertical transport," S. C. Solomon, D. R. Marsh, R. G. Roble, and J. M. Russell III, paper presented at the Annual Spring AGU meeting, May 29-June 1, 2001, Boston, MA.

"A diagnostic analysis of the response of the ionospheric electron temperatures to geomagnetic storms using the thermosphere-ionosphere nested grid model (TING)," W. Wang, T. L. Killeen, A. G. Burns, and R. G. Roble, paper presented at the Annual Spring AGU meeting, May 29-June 1, 2001, Boston, MA.

"Daytime neutral winds in the lower thermosphere for March equinox," S. P. Zhang, L. P. Goncharenko, J. E. Salah, Q Zhou, and R. G. Roble, paper presented at the Annual Spring AGU meeting, May 29-June 1, 2001, Boston, MA.

"Tidal influence on the oxygen and hydroxyl nightglows: WINDII observations and TIME-GCM simulations," S. P. Zhang, R. G. Roble, and G. G. Shepherd, paper presented at the Annual Spring AGU meeting, May 29-June 1, 2001, Boston, MA.

“TIME-GCM overview,” R. G. Roble, invited paper presented at the SEE-TIMED workshop, LASP, University of Colorado, June 11, 2001, Boulder.

“General circulation modeling of the thermosphere and ionosphere,” R. G. Roble, invited paper presented at the TIGER Symposium, June 12-13, 2001, Boulder, CO.

“Modeling upper atmosphere response to increasing greenhouse gases,” R. G. Roble and G. E. Thomas, invited paper presented at the 2001 CEDAR-SCOSTEP meeting, June 18-22, 2001, Longmont, CO.

“The whole atmosphere climate chemistry model: Mean climate, composition, and variability,” F. Sassi, D. Kinnison, B. Boville, R. Garcia, and R. G. Roble, paper presented at the CCSM workshop, June 26-28, 2001, Breckenridge, CO.

“The Whole Atmosphere Community Climate Model (WACCM),” B. A. Boville, D. Kinnison, F. Sassi, R. R. Garcia, and R. G. Roble, paper presented at the AURA/EOS meeting, June 12-14, 2001, Washington, D.C.

“Observations of the atmospheric energy budget from the edge of space to the surface of the earth,” M. G. Mlynczak and R. G. Roble, invited paper presented at the IAMAS meeting, July 16-20, 2001, Innsbruck, Austria.

“The equinox transition,” G. G. Shepherd, M. G. Shepherd, and R. G. Roble, paper presented at the UARS 10th Anniversary Science meeting, September 11-13, 2001, Greenbelt, MD.

“Latest results on the composition and structure of the mesosphere and lower thermosphere as measured by CRISTA,” Kaufmann, M., O. Gusev, K. U. Grossmann, A. A. Kutepov, M. E. Hagan, C. Hartsough, and R. G. Roble, invited paper presented at the IAMAS 2001 Scientific Assembly, July 10-18, 2001, Innsbruck, Austria.